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(54) Composite membrane.

(57) A composite sheet for a filter comprises a porous tape-cast membrane of partly sintered refractory particles, and a microporous inorganic film overlying a surface of the membrane. The microporous inorganic film has a thickness of 0.01 - 2 μ m and is of substantially uniform pore size and substantially free of cracks and pin-holes.

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COMPOSITE MEMBRANE

This invention is concerned with composite membranes which are suitable for separation and filtration processes in the ultrafiltration range. Ultrafiltration is generally accepted to be defined by retention of molecules or particles in the size range 20nm down to 1 nm (1nm = 1 nanometer = 10^{-9} m). An alternative way of expressing this filtration range is by converting molecular size to molecular weight: on this basis it is the retention of species in the molecular weight range of 300,000 down to 300. The main requirements for ultrafiltration membranes are :-

- Available in suitable size and shape, an sufficiently robust to resist accidental damage;
- Resistant to chemicals and heat of the kind likely to be encountered in filtration processes. In this respect, inorganic membranes are generally superior to organic ones.
- A rather uniform pore size. Here again, current polymeric organic ultrafiltration membranes have rather wide pore size distributions; as a result their selectivity is low and their molecular weight cutoff is not sharp.
- Substantial or ideally complete freedom from cracks or pin-holes.
- Having regard to pore size, a high flux (defined as volume passing per unit area per unit time), to permit rapid passage of filtrate. This feature requires not only a large number of pores per unit area, but also that the length of the narrow pores be as short as possible.

US Patent 3,944,658 describes a sol-gel technique for making a porous alumina product. An aluminium alkoxide is hydrolysed in water and peptised with acid to form a clear transparent sol. The sol is gelled and the gel dried and calcined to provide the porous product. It is noted that the sol can be applied as a coating to porous ceramic materials, but this aspect is not further described.

Japan Kokai 60-180979 describes a method of manufacturing a ceramic membrane for separating condensation components. A porous support structure is repeatedly impregnated with an alumina sol, dried and fired, to give a product with fine pores down to about 1nm diameter.

A.F.M. Leenaars and co-workers at Twente University of Technology in Holland have published a series of papers on alumina films produced by sol-gel techniques. An article in Journal of Colloid and Interface Science, vol 105, 1, May 1985, 27 to 39 describes the formation of composite membranes by applying alumina sols to porous alpha-alumina supports. The supports were dipped into the sol for short periods, typically 0.5 seconds and removed, dried and calcined. Calcined layer thicknesses varied from 3 to 8 μ m, but crack-free films could only be obtained with layers less than 5 μ m. The thinnest layers could only be obtained by very short dipping times when thicknesses were largely uncontrolled and highly variable, i.e. plus or minus 0.5 μ m. Significant impregnations of the support by the sol generally took place on dipping.

Articles in Journal of Membrane Science, 24 (1985) pages 245-260 and 261-270 describe the use of such composite membranes in experiments to determine their permeability for pure liquids and their ultrafiltration and hyperfiltration properties. The sol-gel films tested were, after calcining, from 2.5 to 5.5 μ m thick, as a result of which low fluxes were generally obtained. Some pin-holing was present in the films, as a result of which fluxes were in isolated cases larger.

As they stand, the products described in these articles would not be suitable for use as ultrafiltration membranes. It is an object of this invention to overcome these problems and provide composite membranes suitable for use in ultrafiltration.

In one aspect, the invention provides a composite sheet comprising a porous tape-cast inorganic membrane and a microporous inorganic film overlying a surface of the membrane, wherein the microporous inorganic film is of substantially uniform pore size and substantially free of cracks and pinholes. The porous inorganic membrane may be of alumina. The microporous inorganic film has a substantially uniform thickness of from 0.01 to 2.0 μ m.

In another aspect, the invention provides a method of making this composite sheet, which method comprises providing a porous tape-cast inorganic membrane, applying a colloidal sol of an inorganic material or a solution of a polymeric precursor to an inorganic material to a surface of the membrane so as to form a gel layer thereon, and drying and heating the gel to convert it to a microporous inorganic film having a thickness from 0.01 - 2.0 μ m, of substantially uniform pore size and substantially free of cracks and pinholes. The surface of the membrane is preferably pre-treated with a solution of a silicate, borate or phosphate.

The inorganic membrane may be a refractory membrane. Overlying a face of the membrane is a microporous film of an inorganic material which may be refractory, for example a ceramic oxide. It is envisaged that this may be an oxide of aluminium, titanium, zirconium, silicon, tantalum, cerium, hafnium, yttrium, thorium, tin, germanium, indium vanadium, niobium, iron, chromium, cobalt, boron and combinations thereof.

The thickness of the microporous film is preferably substantially uniform over the surface of the membrane, from 0.01 to 2.0 μm , preferably from 0.03 to 0.5 μm . The thicker the microporous film the lower is the liquid flux obtainable through it on ultrafiltration, and for this reason a preferred maximum limit is set at 2 μm .

The films contain pores of substantially uniform pore size and substantially free of cracks and pin-holes. The average pore size is preferably from 0.5 to 30nm, particularly 1 to 4nm, and pores more than twice the average size are preferably substantially absent.

The method of the invention involves applying a colloidal sol of an inorganic material (such as a ceramic oxide) or a solution of a polymeric precursor to an inorganic material (such as a metal oxide) to one or both faces of the membrane. The colloidal sol may be derived by known means from an inorganic oxide powder, such as an oxide of the elements mentioned above. More preferably the colloidal sol or polymeric solution is derived by hydrolysis of a metal alkoxide. For example, boehmite sols may be prepared using the procedure described in US Patent 3,944,658. According to this procedure, an aluminium alkoxide is hydrolysed in an excess of water maintained at 80°C, and subsequently peptized with an acid, to form a clear transparent sol. The sol consists of colloidal particles of stable crystalline aluminium monohydrate, $\text{AlO}(\text{OH})$, dispersed in the aqueous phase. The sol so produced typically contains about 30 gl^{-1} of aluminium values expressed as Al_2O_3 , and can be adjusted to the desired concentration for coating by dilution with water or evaporation. Coatings may be achieved with sols of concentration up to 190 gl^{-1} , preferably 10 gl^{-1} to 90 gl^{-1} , of aluminium values expressed as Al_2O_3 . As an alternative example, -Ti-O-Ti- polymer solutions may be prepared using a procedure similar to that described in the article by C J Brinker and M S Harrington in Solar Energy Materials, 1981, volume 5, 159-172, wherein a titanium alkoxide is partially hydrolysed in an alcoholic solution at room temperature in the presence of an acid catalyst to form a stable -Ti-O-Ti- polymer solution. The solution so produced typically contains about 10 to 30 gl^{-1} of titanium values expressed as TiO_2 , and can be adjusted to the desired concentration for coating by evaporation of solvent or further dilution with alcohol. The sol or solution can be applied to the anodic oxide membrane in the freshly concentrated state, or aged to increase its viscosity prior to application. Control over the film thickness in the composite membrane can be achieved in part by control over the concentration and viscosity of the sol prior to application.

Prior to sol deposition, it may be advantageous to pre-treat the membrane, by immersion in a solution of a silicate, phosphate or borate. The effect of this pre-treatment can be to permit the subsequent formation of a gel layer giving substantially complete coverage of the membrane more easily than is possible without the pre-treatment. The mechanism by which this desirable effect is achieved is not fully understood, but the pretreatment may improve the wettability of the membrane surface, and may deposit on or react with the surface to form a layer which is receptive to the sol and helps to gel it. The solution may be, in order of decreasing preference, an aqueous solution of an alkali metal metasilicate such as sodium metasilicate, an alkali metal triphosphate particularly pentasodium triphosphate, or an alkali metal borate such as disodium tetraborate. The concentration is preferably from 1% up to saturation, typically in the range 3 to 5 percent by weight. The temperature may be ambient such as from 10 to 30°C. The period of immersion of the membrane in the solution is generally in the range 1 second to 10 minutes, and may typically be around 5 seconds. Immersion time needs to be adjusted, in relation to the other process variables, to be sufficient to modify the surface of the membrane, but not so great as to deposit substantial amounts of material in a way that might reduce the diameter of the pores or even block them completely. This should be followed by rinsing the membrane in distilled water.

Addition of a surface active agent to the sol prior to application aids the formation of thin uniform gel layers. Non ionic surfactants such as Nonidet (Octylphenyl ethylene oxide condensate supplied by BDH Chemicals), or Methocel (methyl cellulose polymer supplied by Dow Chemical Company) added typically at the concentration level of 0.1 to 1 percent by weight, can result in thinner uniform gel layers than are obtained with unmodified sol.

The thin uniform gel films can be formed on the second surface of the membrane by deposition of a concentrated sol followed by air drying. Various techniques including brush, spray, dip, spin coating, electrophoretic and thermophoretic techniques may be used to apply the sol to the membrane. Spray coatings can be applied using an aerosol method. The anodic oxide membrane is suspended vertically to permit excess sol to drain off and spraying is conducted until full coverage of the membrane surface is achieved.

To prepare spin coated composite membranes, the membrane can be attached horizontally to the platen of a commercially available spin coating unit. A known quantity of the concentrated sol is applied to the membrane surface and is permitted to reside thereon for a predetermined period of time typically up to 60 seconds. Excess sol is removed by spinning the coated membrane, typically at a speed from 200 to

2000 rpm. The thickness of the gel film is controlled by the sol concentration and age, the residence time of the sol on the membrane surface, and the spin speed and spin time.

The freshly coated membrane is then heated to transform the gel layer into a microporous refractory film. For example, heating converts a boehmite gel layer into a mechanically stable gamma- Al_2O_3 structure.

Heating conditions are not critical to the invention and may be conventional, bearing in mind the need to avoid thermal shock which might result in the formation of cracks or pin-holes. A typical heating schedule for a boehmite gel layer might be: (a) heating at 50°C per hour to 200°C followed by isothermal treatment at 200°C for 15 minutes, (b) subsequent heating at 200°C per hour to 450°C followed by an isothermal hold for 15 minutes, (c) cooling at 50°C per hour to room temperature. The first part of the heating schedule up to 200°C is designed to remove absorbed water; the second stage to 450°C removes bound water and transforms the gamma- AlOOH to gamma- Al_2O_3 . This transformation occurs at temperatures at or above 390°C. During the heating operation, considerable shrinkage of the film takes place. For films of the thickness with which this invention is concerned, shrinkage is mainly in a direction perpendicular to the plane of the film, i.e. the film gets thinner. For thicker films, shrinkage may be in the plane of the film and may result in cracking.

It is possible to use a tape-cast membrane, which may have larger pores or may not have been pre-treated with a silicate or other solution, and to achieve complete coverage by a film having the desired microporous structure by two or more successive sol/gel applications. Thus, a first aqueous sol may be applied to the membrane and the resulting gel optionally dried and heated; and a second sol, aqueous or alcoholic, may be applied to the thus-formed gel or microporous film and the resulting gel or gels dried and heated. The membrane is completely covered by two superimposed microporous films which may be arranged to have the same or different pore sizes and which should be completely free of cracks and pinholes.

In order to prevent the ingress of the colloidal sol (or solution of a polymeric precursor or to an inorganic material) into the pores of the membrane, it is possible to increase its viscosity. This can be done simply by adding a relatively viscous miscible organic liquid. Alternatively, a relatively viscous relatively high boiling point liquid, for example a polymer such as polyvinyl alcohol or a polyol such as ethylene glycol or glycerol, may be added to the colloidal sol (or solution of a polymeric precursor) and thereafter boiled to remove some or all of the less viscous liquid but without breaking down the colloidal dispersion or solution of inorganic material.

EXPERIMENTAL PROCEDURE 1 ALUMINA COATINGS

There follows a description of the preparation and concentration of a boehmite sol.

In a typical experiment, the boehmite sol was prepared by adding aluminium secondary butoxide (1 mole) to deionised water (1.8 l) which was heated to a temperature above 80°C. The mixture was stirred vigorously and maintained at 90°C. One hour after the addition of the alkoxide, nitric acid (0.07 mole) was added to peptize the sol. The sol was kept boiling in an open reactor for about 2 hours to evaporate most of the secondary butanol and then maintained at 90°C under reflux conditions for a further 16 hours, until a clear transparent sol was obtained.

Some typical properties of the sol were determined to be:

Concentration	29.8 gl^{-1} Al_2O_3
pH	4.00
Conductivity	2.20 mmhos, 21°C
Viscosity	5 centipose, 21°C

The pH, conductivity and viscosity of the sol remained unchanged over a period of one month when the sol was kept at RT (21°C).

Boehmite sols so prepared, containing 30 grammes per litre of Al_2O_3 , can be evaporated by heating in air to produce concentrated sols containing up to 190 grammes per litre of Al_2O_3 , or diluted by addition of water to concentration below 10 gl^{-1} . The sols can either be used for coating in the freshly concentrated state, or aged to increase their viscosity prior to coating. The room temperature (21°C) ageing characteristics of a sol concentrated to 62 grammes per litre of Al_2O_3 over a period of one month were determined to be:

Age of sol (days)	pH	Conductivity (mmhos)	Viscosity (cp)
0	3.72	5.11	5
10	3.80	4.48	6
20	3.83	4.70	7
30	3.83	4.44	8

10 All measurements were conducted at 21°C.

EXPERIMENTAL PROCEDURE 2 TITANIA COATINGS

15 There follows a description of the preparation of a partially hydrolysed titanium alkoxide derived polymer solution which can be deposited upon a porous refractory support and calcined to result in a microporous film of titania.

20 In a typical experiment, the polymer solution was prepared by adding titanium isopropoxide (0.012 mole) to 50 cm³ isopropanol under anhydrous conditions at room temperature. Deionised water (0.017 mole) was added to a second 50 cm³ volume of isopropanol at room temperature. The water/alcohol solution was added dropwise while stirring at room temperature to the alkoxide/alcohol solution. Partial hydrolysis and polymerisation of the alkoxide resulted. An acid catalyst, typically HNO₃ (0.006 mole) was added to the solution to cause peptization. A clear solution resulted, of concentration 10 gl⁻¹ of titanium values expressed as TiO₂, of viscosity 3 cp (21°C).

25 The titanium polymer solution so prepared can be concentrated to greater than 30 gl⁻¹ of titanium values expressed as TiO₂, but is preferably used for film deposition at a concentration of 10 gl⁻¹ of titanium values expressed as TiO₂.

30 EXAMPLE 1

165 g of alumina and 0.42 g of magnesia were slurried in a liquid system composed of 78 g trichloroethylene, 32 g of ethanol, 3.8 g of corn oil, 8.4 g of polyvinyl butyral and 14.2 g of polyethylene glycol. The slurry was tape-cast on a glass substrate into a film of width 173 mm, which was dried in air to yield a flexible tape of thickness 0.14 mm. Discs of diameter 26 mm were cut from the tape and partially sintered to produce a porous ceramic material of average pore size 0.3 µm. The discs were pretreated by immersion for 5 seconds in a 5% solution of sodium metasilicate, and subsequently spray coated with a viscous boehmite sol of concentration 15 gl⁻¹ in which the water had been replaced by diethylene glycol by adding 100 ml of diethylene glycol to 50 ml of sol at a concentration of 30 gl⁻¹ and boiling to evaporate to 100 ml to increase the viscosity. The coated porous substrate was heated for 1 hour at 450°C to transform the gel layer into a stable γ-Al₂O₃ film containing pores of slit width 4.2 nm.

40 An aqueous boehmite sol of concentration 30 gl⁻¹ was subsequently deposited upon the first sol-gel layer by spray coating. This was followed by heating for 1 hour at 450°C, which produced a stable γ-Al₂O₃ film of pore slit width 2.8 nm. The composite ultra filtration membrane thus formed had a total coating thickness of 1 µm and a pure water flux at 110 kPa of 0.016 ml min⁻¹ cm⁻².

Claims

1. A composite sheet comprising a porous tape-cast inorganic membrane and a microporous inorganic film overlying a surface of the membrane, wherein the microporous inorganic film has a thickness from 0.01 to 2.0 µm and is of substantially uniform pore size and substantially free of cracks and pinholes.
2. A composite sheet as claimed in claim 1, wherein the porous inorganic membrane is of alumina.
3. A composite sheet as claimed in any one of claims 1 to 2, wherein the microporous film is from 0.01 to 2.0 µm thick.
4. A composite sheet as claimed in any one claims 1 to 3, wherein the microporous inorganic film is of a metal oxide.
5. A composite sheet as claimed in claim 4, wherein the microporous inorganic film is of gamma-

alumina.

6. A composite sheet as claimed in any one of claims 1 to 5, wherein the average pore size of the microporous film is from 0.5 to 30nm.

7. A method of making a composite sheet, which method comprises providing a porous tape-cast inorganic membrane, applying a colloidal sol of an inorganic material or a solution of a polymeric precursor to an inorganic material to a surface thereof so as to form a gel layer thereon and drying and heating the gel to convert it to a microporous inorganic film having a thickness from 0.01 - 2.0 μm , of substantially uniform pore size and substantially free of cracks and pinholes.

8. A method as claimed in claim 7, which method comprises pretreating a surface of the membrane with a solution of a silicate, borate or phosphate, applying to the pretreated surface a colloidal sol of an inorganic material or a solution of a polymeric precursor to an inorganic material so as to form thereon a gel layer, and drying and heating the gel to convert it to a microporous inorganic film of substantially uniform pore size and substantially free of cracks and pinholes.

9. A method as claimed in claim 8, wherein pretreatment is effected by contacting the porous membrane with an aqueous solution of the silicate, borate or phosphate at a concentration of at least 1% by weight and a temperature of 0 to 50°C for a contact time of from 1 second to 10 minutes.

10. A method as claimed in any one of claims 9, wherein the colloidal sol is of a refractory metal oxide or the solution is of a polymeric precursor to a metal oxide.

11. A method as claimed in claim 10, wherein the colloidal sol is a boehmite sol obtained by hydrolysis of an aluminium alkoxide

12. A method as claimed in claim 10, wherein the solution of a polymeric precursor to a metal oxide is a solution obtained by partial hydrolysis of a titanium alkoxide.

13. A method as claimed in any one of claims 7 to 12, wherein the colloidal sol or solution contains a surface active agent.

14. A method as claimed in any one of claims 7 to 13, wherein the colloidal sol or solution is applied to the porous membrane by a spray coating method.

15. A method as claimed in any one of claims 7 to 14, wherein the colloidal sol or solution is applied to the membrane by a spin-coating method.

16. A method as claimed in any one of claims 7 to 15, which method comprises providing a colloidal sol of an inorganic material or a solution of a polymeric precursor to an inorganic material, increasing the viscosity of the sol or solution by adding a relatively viscous miscible organic liquid, applying the more viscous sol or solution to a surface of the membrane so as to form thereon a gel layer, and drying and heating the gel to convert it to a microporous inorganic film of substantially uniform pore size and substantially free of cracks and pinholes.

17. A filter comprising a composite sheet as claimed in any one of claims 1 to 6.



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EUROPEAN SEARCH REPORT

Application Number

EP 90 11 2090

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 5)
A	EP-A-0 136 937 (CERAVER) * Abstract; claim 1; page 1, lines 30-35; example 1; page 5, lines 13-16; page 6, lines 12-14 *	1,3-7, 10-13, 16,17	B 01 D 71/02 C 04 B 38/00
A	VIDE, vol. 40, no. 227, May-June-July 1985, pages 277-280, Paris, FR; C. GUIZARD et al.: "Utilisation des procédés "sol-gel" pour l'obtention de couches minces céramiques" * Page 277, lines 20-42; page 278, lines 34-39; page 279, lines 43-44; page 280, lines 1-6 *	1,3,4,7 10,12, 17	
A	EP-A-0 144 097 (ECN, NETHERLANDS ENERGY RESEARCH FOUND.) * Abstract; claims 1,2,11; page 3, lines 1-6; page 4, lines 18-20; page 5, lines 14-26; page 5, line 34 - page 6, line 2; page 7, lines 9-18 *	1-7,10, 11,17	
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A	GB-A-1 605 248 (THE MOND NICKEL CO., LTD) * Claims 1,2,5,9-11,15,17,18; page 1, lines 13-18,33-40; page 4, lines 12-25,100-104; figures 1,2 *	1,7,16, 17	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 08-08-1990	Examiner HOORNAERT P.G.R.J.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document			

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A	CHEMICAL ABSTRACTS, vol. 93, no. 12, 22nd September 1980, page 264, abstract no. 119053e, Columbus, Ohio, US; G. DE PORTU et al.: "Young's modulus-porosity relationship for alumina substrates", & CERAMURGIA INT. 1979, 5(4), 165-7 * Abstract *	1,2,7	
A	US-A-4 353 958 (K. KITA) * Abstract; column 1, lines 53-65; examples *	1,2,7	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
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CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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